Ethology as an Inspiration for Adaptive Behavior Synthesis in Autonomous Planetary Rovers

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Outline

- Concepts from ethology
- Manifestations in rover navigation
- Simulation examples
- Behavioral interactions
- Conclusions

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Analysis↔Synthesis Premise

- Ethologists analyze animal behavior and develop models & explanations based upon external observations (outside-in)

- Roboticists seek to synthesize (animal-/human-like) intelligent behavior in robots by implementing computational algorithms and electronic circuitry (inside-out)

- Conceptual models from ethology are useful starting points for intelligent behavior synthesis in robots

Concepts from ethology

- Hierarchical organization of behavior — instinct levels, innate releasing mechanisms, fixed action patterns, primitive motor activities.

- Concurrent activation and coordination of motivational tendencies (multi-behavior action selection)

- Behavior excitation and inhibition via threshold activation

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Examples from ethology

- Incubation behavior of the herring gull (G. P. Baerends. 1970)

- Tinbergen's hierarchy of instinct centers (1951)

- MacLean's triune brain concept (1973)

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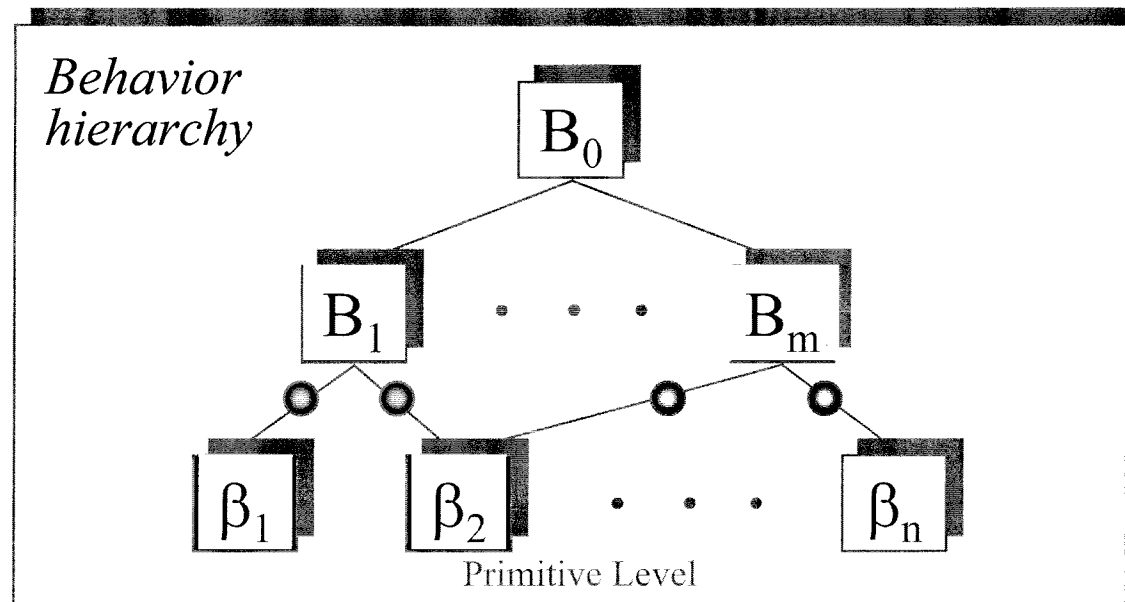tunstel@robotics.jpl.nasa.gov
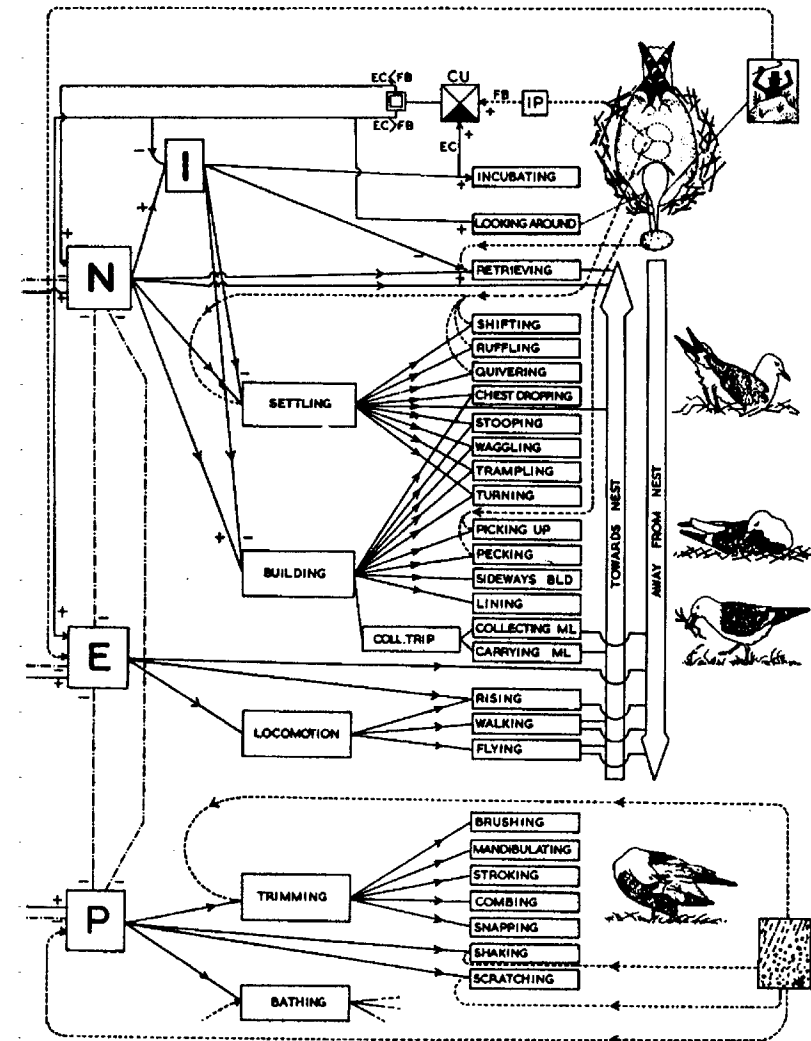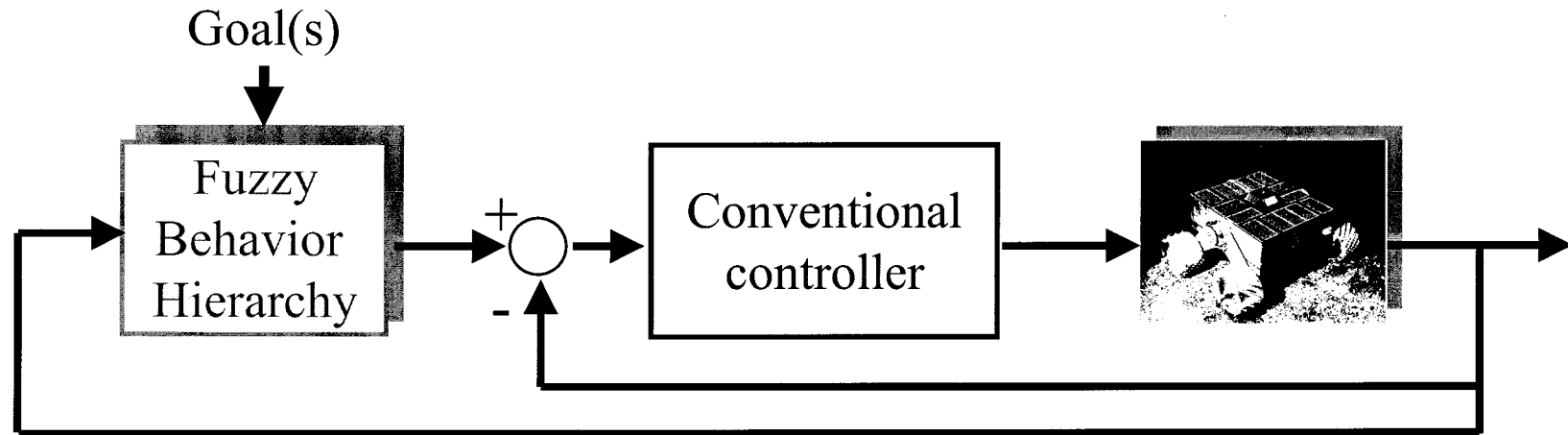
Real world rover navigation

- Negotiation of natural and rough terrain

- Autonomy constrained by limited power, computation, and communications bandwidth

- State-of-the-art processors not widely available for space applications

=> Need for flexible control architectures and efficient algorithms
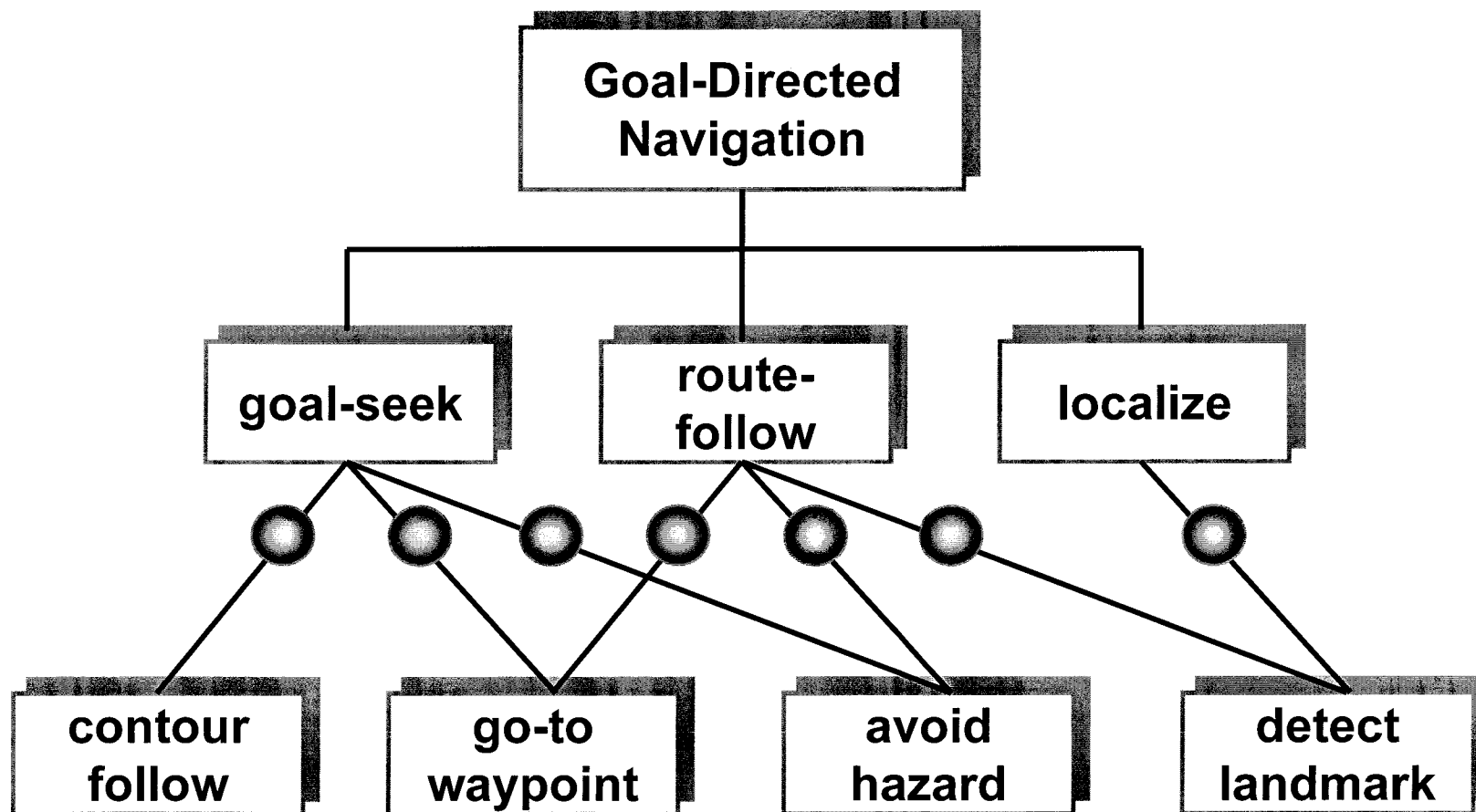
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Hierarchical behavior structure

- Autonomous motion behavior can be conveniently decomposed into a bottom-up hierarchy of increasing capabilities

- *Primitive behaviors*

  ~ simple; special-purpose

  ~ maps from perception to actuators (stimuli to response)

  ~ solipsist

- *Composite behaviors*

  ~ modulate activation of primitives for task execution

  ~ decision modules that coordinate concurrent primitives

  ~ motivational, goal-oriented

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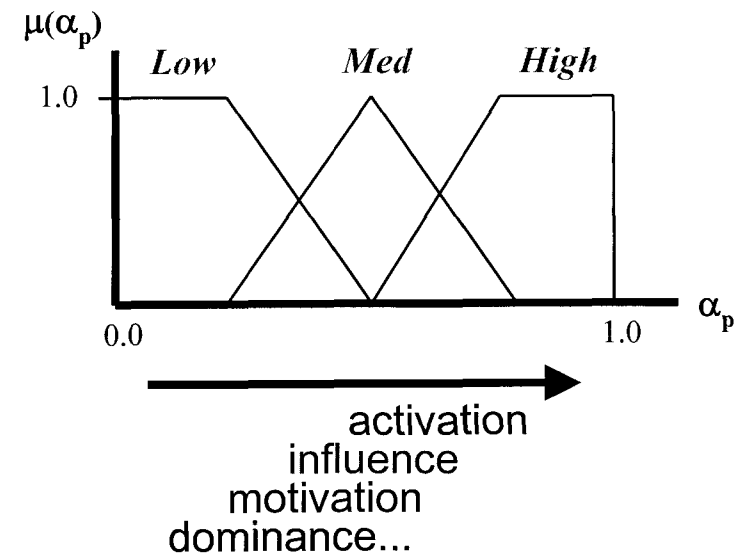
Multi-rule-base FLC

Goal(s)

```
┌─────────────┐          ┌──────────────┐
│   Fuzzy     │    +     │ Conventional │
│  Behavior   │──→ ○ ──→ │  controller  │──→
│  Hierarchy  │    -     │              │
└─────────────┘          └──────────────┘
```

Behavior hierarchy

B_0

B_1 $\cdots$ B_m

β_1 β_2 $\cdots$ β_n

Primitive Level

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Rover navigation behavior hierarchy

```
                    Goal-Directed
                     Navigation
                          |
        _____
       |                   |                    |
   goal-seek          route-             localize
                      follow
```

- contour follow
- go-to waypoint
- avoid hazard
- detect landmark

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Behavior Modulation: coordination

- Decision-making mechanism among fuzzy-behaviors based on dynamically adaptive weights

- Composite behaviors govern *continuous* activation levels of *applicable* primitive behaviors

- Coordination based on Degree Of Applicability (DOA), α_j

    applicability rule:
    IF *obstacle is Near* and *goal is Far*
    THEN α_1 *is High;* α_2 *is Low*

$\mu(\alpha_p)$

Low   *Med*   *High*

1.0

0.0   1.0 α_p

activation
influence
motivation
dominance...

- DOAs adapt the control mapping from perceptions to actions
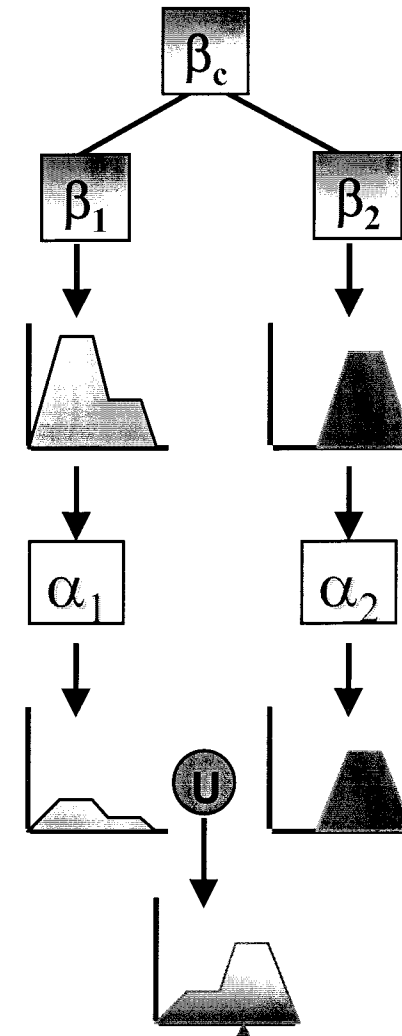
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Multi-behavior decision making

- Activation levels (weights) govern individual behavioral influence
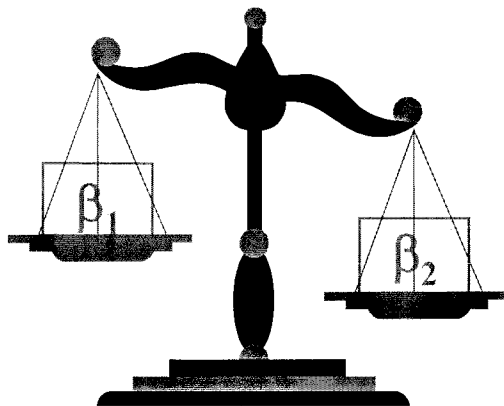
- Control decision is a consensus among all *applicable* behaviors
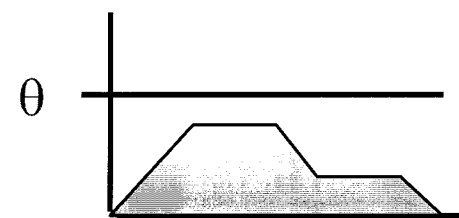
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Threshold Activation

- Consideration of behavior output thresholds, θ

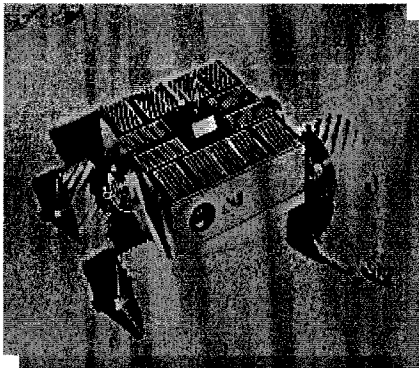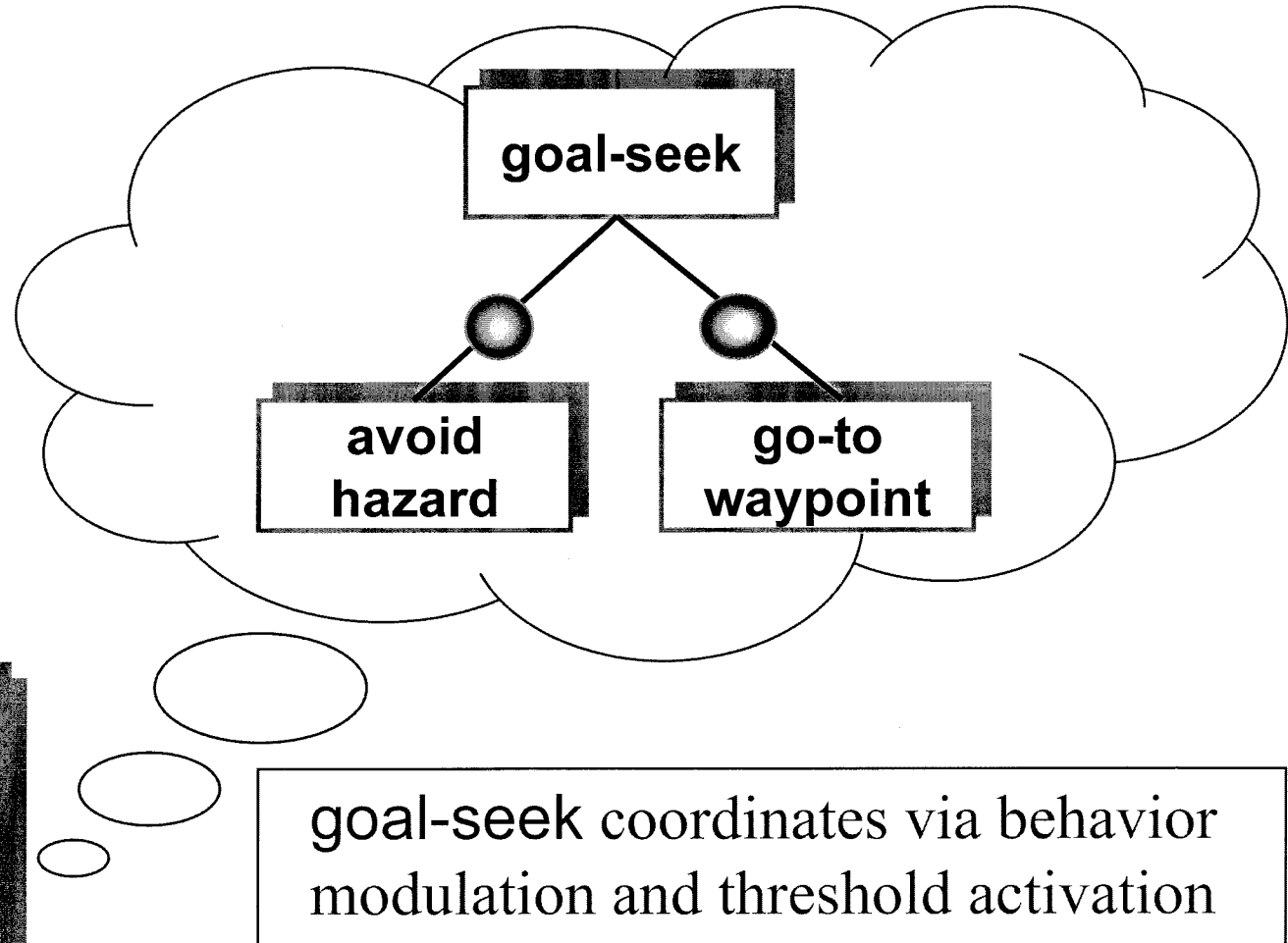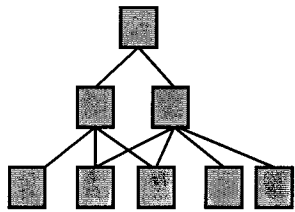θ ... non-null alpha-cut
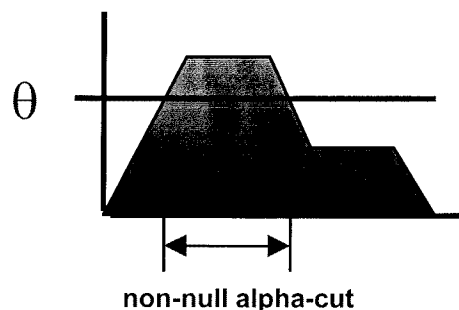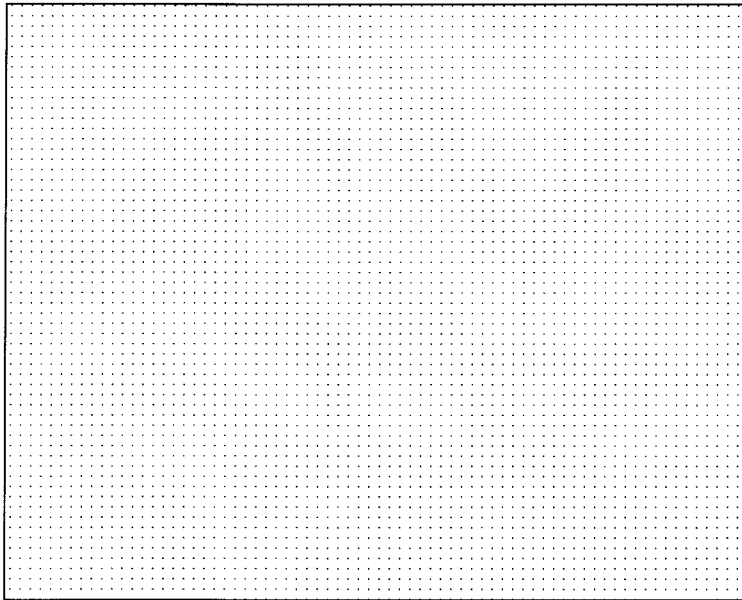
activated   *non-activated*

- Activate if stimuli exceed activation threshold
- Behavior *selection* is a special case

$$[(\alpha_i > 0) \wedge (\alpha_i > \theta_i)] \wedge [(\alpha_j = 0) \vee (\alpha_j < \theta_j)], \forall i \neq j$$

- tunable "knobs", θ_i, enable further adaptation

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Behavior hierarchy: local navigation

goal-seek

avoid
hazard

go-to
waypoint

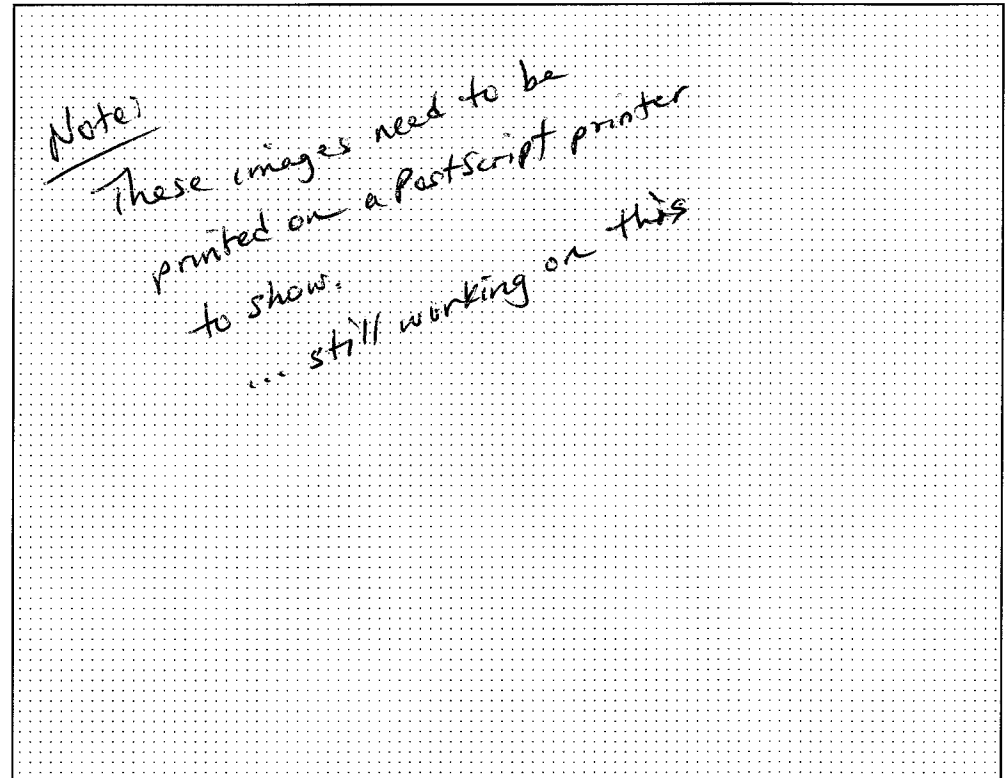goal-seek coordinates via behavior modulation and threshold activation

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Simulated performance: threshold activation

Nominal performance without
threshold activation (failure)

Performance with threshold activation: $\theta_{ah}=0.5$, $\theta_{gt}=0.0025$

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Simulated performance: behavior interaction

Image being converted for inclusion later

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Concluding remarks

- Ethological concepts and models of behavior can be tailored for application to rover navigation
- Implementations of behavior hierarchies, multi-behavior modulation, and threshold activation can provide a facility for situated adaptation in rover control algorithms
- Adjustable thresholds provide tunable "knobs" that permit performance refinement in practice (simpler than rule or parameter tuning after deployment)
- The bio-inspired approach has potential as a conceptual model of intelligent behavior and behavioral relationships
- As ethologists study behavior from the outside, and roboticists concentrate on synthesis from the inside, perhaps we will converge at a unified understanding of intelligence

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